A METHOD FOR CORRECTING A DAMAGED TACHO SIGNAL

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Abstract: Order analysis of vibration signals from rotary machinery typically uses tacho sensors utilizing either optical or magnetic principle for precise measurement of shaft angle position that can be calculated to the rotational speed. In some cases, the tacho signal can be distorted in numerous ways, for example, the presence of additional corrupting edges that show up as strong damage to the speed profile. This paper introduces an automatic algorithmic technique to remove corrupting edges from the tacho signal via a criterion-based approach called. The properties of the method are demonstrated on a simple theoretical example as well as on a real signal from a turbojet run-up that exhibits superior functionality even during rapid speed changes; such variations are typically problematic. The procedure also preserves a number of correct edges even when the corrupting edge is very close to the correct one.

Keywords: tacho, speed profile, distortion, order analysis

1 INTRODUCTION

Tacho probes are typically used as a sensor for measuring instantaneous rotational speed of rotary machinery, because all order tracking methods need such information to process the signal, typically an acceleration, correctly [1]. This group of sensors usually utilizes magnetic or optical principle and measures the time when particular shaft position occurs, sometimes the arrangement allow to measure multiple positions that are intended to be uniform [2]. Output of this type of sensors is typically series of pulses that indicate passing the particular shaft position. The speed profile can be obtained also directly from the vibration signal that is greatly useful, when the rotational speed was not measured [3, 4]. These methods can fail when there is low signal-to-noise ratio or when different source of noise is present in the signal. Also, these methods need a priori information set by a user.

A tacho signal can be acquired once (or multiple times) per shaft revolution. In this arrangement, only average rotational speed can be calculated. This applies also to the situation when multiple edges per the revolution are acquired. Although the speed is obtained more times per revolution, due to non-uniform distribution of the edges, time duration of one edge against the same one should be calculated to avoid errors originating from non-uniform distribution.

When the tacho signal is already acquired it is meaningful to use it because its precision is sufficient in most of cases. This paper deals with tacho signal that is damaged by an additional corrupting edges. Any corrupting edge near to correct one would cause major error of the speed profile and make it impossible to use. Since the error is significant, even filtration does not help. Therefore, direct removal of the additional edges is important. Presented method can flawlessly remove such edges automatically with an easy initial settings. As a result, the speed profile is not affected in any way and can be used by number of order tracking methods, namely computed order tracking (COT) or Vold-Kalman filter [5, 6].

2 THE CRITERION-BASED METHOD

The method works with the absolute times of all acquired edges. Times of four consecutive edges labeled e_i to e_{i+3} are considered with a condition that there cannot be any corrupting edge between the edges e_0 and e_1. If the edges will be spaced equally, result of the criterion consisting of the following equations

$$K = (k_{1,i} - 1)^2 + (k_{2,i} - 1)^2 , \tag{1}$$

$$k_{1,i} = \frac{e_{i+2} - e_{i+1}}{e_{i+1} - e_i} , \tag{2}$$

$$k_{2,i} = \frac{e_{i+3} - e_{i+2}}{e_{i+1} - e_i} , \tag{3}$$

is zero. Variable i works as an indication of current iteration of the algorithm. If the edge e_{i+3} is replaced by corrupting edge that takes place before, value of Eq. (3) increases. An algorithm can try to anticipate such corrupting edge, and calculates the criterion (1) with the correct edge after e_{i+3}. In this case, the criterion value will be lower. This principle can be generalized to the situation that the algorithm will assume that up to C corrupting edges can be placed between correct edges e_{i+1} and e_{i+2}, and also up to C corrupting edges can be placed between edges e_{i+2} and e_{i+3}. The algorithm will calculate the criterion (1) for every combination and selects the one with the lowest value. Then shifts edges e_i and e_{i+1} to the following ones that were selected by the criterion and repeats the mentioned steps (while incrementing iterator i) until whole series of edges is processed.

All values of actual speed profile f are calculated using formula

$$f_j = \frac{1}{e_{j+1} - e_j} , \tag{4}$$

that calculates local frequency of edges occurrence, parameter j stands for position of edges in the series. Since edges have indexes in range $\langle 0; N-1 \rangle$, calculated frequencies have indexes in the range $\langle 0; N-2 \rangle$, because there is only $N-1$ such frequencies if N denotes total number of edges. The unit for the speed profile can be number of revolutions per second or hertz. It is obvious from the equation (4) that any additional edge creates disturbing peak in the speed profile if one edge per revolution is expected.

2.1 ILLUSTRATIVE EXAMPLE

In this section, the method will be explained more in detail using a simple example. An artificial sequence of the edges is illustrated in Fig. 1. Times of correct edges are blue while the corrupting ones are red. Spacing of the correct edges is uniform and maximum number of corrupting edges C is set to 3. In the beginning, combinations of edges

$$\{0, 1, 2, 3\}$$

is considered and criterion is calculated. At first, the situation when the fourth edge can be corrupting is handled by calculating the criterion for shifting the fourth edge resulting in criterion values for combination of edges

$$\{0, 1, 2, 4\} , \quad \{0, 1, 2, 5\} , \quad \{0, 1, 2, 6\} .$$

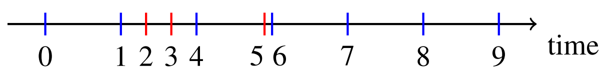

Figure 1: An time arrangement of the edges used in illustrative example. Blue edges are correct, red are corrupting.

Also, the third edge can be corrupting, therefore the third and fourth edges are shifted together resulting in combination of edges

$$\{0,1,3,4\}, \quad \{0,1,4,5\}, \quad \{0,1,5,6\}.$$

None of combinations is clearly the desired sequence of edges. At last, combination of both situations described above can create additional 9 sequences since number of all combinations is equal to $(C+1)^2 = 4^2 = 16$. The rest of 9 combinations is listed below

$$\begin{array}{lll} \{0,1,3,5\}, & \{0,1,3,6\}, & \{0,1,3,7\}, \\ \{\mathbf{0},\mathbf{1},\mathbf{4},\mathbf{6}\}, & \{0,1,4,7\}, & \{0,1,4,8\}, \\ \{0,1,5,7\}, & \{0,1,5,8\}, & \{0,1,5,9\}. \end{array}$$

The combination with the lowest criterion value is in bold text. If the combination with the lowest criterion value skips some edges, these are not used in following iterations. In the next iteration, combination of edges

$$\{1,4,6,7\}$$

is considered and the same process of calculating the criterion value for all combinations starts over.

3 EXPERIMENTAL VERIFICATION OF THE METHOD

The machine used to show quality of proposed method is a turbojet with 20 blades at a compression section. Presence of the blade was measured by inductive proximity sensor faced radially to the axis of rotation, therefore 20 pulses can be seen in the signal during one revolution. The signal was digitized by acquisition card with sampling frequency of 1 MHz to achieve fine time resolution. Only rising edges were obtained using simple algorithm that calculates the time when the signal crosses a user-specified threshold. The signal contains many corrupting edges due to a noise present in the signal trace that could not be fixed during the measurement. The speed profile without filtering false edges is showed in Fig. 2 on the left. The speed profile is calculated using the edge from the same blade, i.e. edges 1 and 20 or 2 and 21 are processed because this approach can reduce the effect of non-uniform distribution of edges coming from 20 blades. Due to presence of corrupting edges, many false peaks can be seen and overall speed profile is nearly impossible to use.

When the method is utilized, initial section of the series of the edges must be selected with the condition that there cannot be any additional edge between initial edges s_0 and s_1. User must also specify maximum number of corrupting edges, in this example 5 edges are sufficient. Although this number can be arbitrarily high, computational complexity should be taken into consideration.

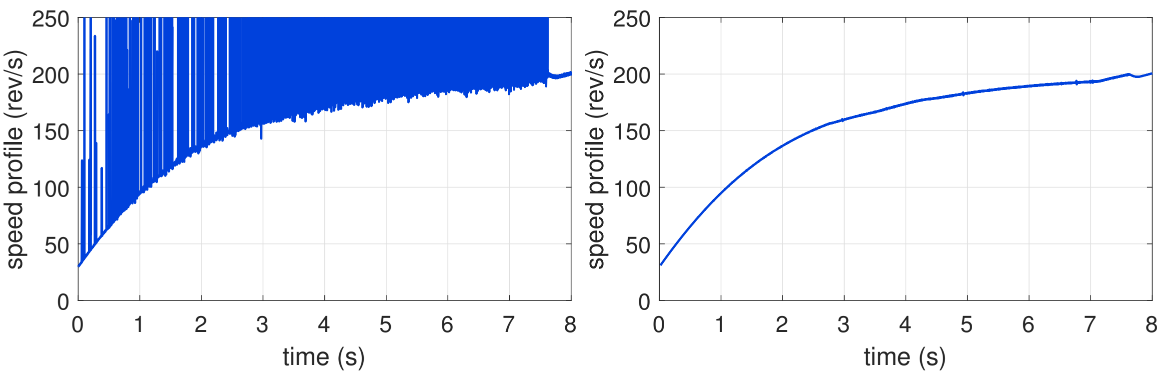

Figure 2: Speed profile without (left) and with a processing by the proposed method (right).

With the criterion (1), first four samples are processed and combination of edges with the lowest criterion value will be used for following iteration. The same process of creating the speed profile as for previous situation leads to speed profile shown in Fig. 2 on the right. It is clear that this speed profile is correct and can be used as a reference for order tracking methods. From total number of 26879 showed edges, there were 1840 edges removed that is approximately 7 % of all edges. This is not possible to achieve manually. Another advantage is that if two edges are really close, the algorithm selects only one of them. Even if the selected one is not the correct one, local disturbance in the speed profile will not be significant.

4 CONCLUSION

The paper described the method that can remove corrupting edges from a tacho signal. The method uses a criterion-based algorithm that adapts to the signal and therefore can handle steady states as well as the transients – run-ups and run-downs. The only condition that must be fulfilled is to select two edges that do not have any corrupting edge in between and the rest is done automatically by the algorithm. Also, user has to select expected maximum number of corrupting edges that must not be exceeded in the signal. Otherwise, the result will be incorrect. Experimental data indicates very good performance of the algorithm, especially during rapid rotational speed changes. Another advantage is possibility to implement this algorithm to a field-programmable gate array (FPGA) or a signal processor, so all processing including edge detection and filtering could be done in a real-time manner. One of the future improvements can be handling of unequal distribution of the edges in a case of multiple edges per one revolution because the presented method can handle only the situation when the unequal distribution of edges is slight.

ACKNOWLEDGEMENT

The completion of this paper was made possible by the grant No. FEKT-S-17-4234 - "Industry 4.0 in automation and cybernetics" financially supported by the Internal science fund of Brno University of Technology.

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